Ultrasonic solution to steam metering

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Rising energy costs make accurately measuring steam consumption more critical for universities and district heating plants. Traditional flow meter technologies used for this type of measurement typically include orifice plates, turbine meters and vortex shedders. While these options provide good accuracy, they lose sensitivity at lower flow rates (poor turndown) and cause pressure drops that rob steam of valuable energy. More and more steam users, including Yale University and a power plant in Washington, D.C., are turning to an ultrasonic solution for steam flow measurement.

Why measure steam?

When you have district heating, measuring the amount of steam consumption at various points in the distribution is beneficial. Billing, efficiency studies, control, and energy rebates are all reasons utility directors have an interest in measuring steam.

Jim Hawthorne, manager of Distribution and Metering at Yale University in New Haven, Connecticut, is concerned with accurate steam flow readings for billing purposes on campus. Yale has more than 200 buildings that use steam from two main power plants. Hawthorne is responsible for maintenance of all steam and chilled water piping between power plants and buildings, including traps, valves, manholes, steam tunnels and steam pressure relief valves.

Casey Phelps, a utilities engineer in Washington, D.C., was tasked with setting up steam flow measurements at more than 100 points on Capitol Hill. With federal guidelines requiring a reduction in energy, Phelps needed to accurately account for steam usage by the government.

Traditional methods

For some 30 years Yale used vortex shedders and turbine meters for measuring steam usage. Vortex shedders determine flow rate by measuring the frequency of vortices shed off a bluff body in the flow stream. Turbine meters have a free turning rotor that spins proportional to flow rate. “Calibration errors on these two technologies were always a problem,” said Hawthorne. “Replacing rotors on turbine meters is required every six months for accuracy.”

Measuring liquid condensate was also an alternative, albeit less direct way of measuring steam consumption at Yale. The condensate is proportional to the amount of steam used. However, leaking traps, pulsating flow from return pumps, draining return pipes, and reverse flow due to faulty back flow preventers make condensate measurement a less accurate option for measuring steam.

Steam distribution at the Washington, D.C. power plant was measured with various flow technologies, including orifice plates and vortex shedders. Orifice plates use the differential pressure across the orifice to measure flow rate. They typically provide good accuracy, but lack the ability to measure lower flow rates, need frequent recalibration, and cause a significant drop in system pressure. The meters had no communications and were difficult to access in confined spaces in order to obtain a manual reading. According to Phelps, considerable costs were involved in maintaining and reading these meters. He needed to find a more accurate and maintenance-free solution that also would communicate with the power plant’s data acquisition system.

Why use ultrasonic?

Ultrasonic technology provides significant advantages over traditional technologies. Yale chose ultrasonic said Hawthorne, because “they have a high turndown ratio, which means we can measure steam during the seasons when consumption is typically low.” A single ultrasonic flow meter can cover a wide range of flows, giving additional savings. Because of their limited turndown ratios, conventional meters are used in multiple runs to cover all steam flow rates during high and low demand periods. Using a single ultrasonic flow meter to cover the full range can result in lower capital and installation costs.

In addition to a high turndown, ultrasonic meters provide no pressure drop. When measuring steam flow rate, pressure drop caused by orifice or vortex shedding meters robs energy from the steam, reducing the amount of power and heat delivered to the user. By using a flow meter with two ultrasonic transducers that do not protrude into the flow stream, transducer installation causes no pressure drop and reduces steam generation costs.

Ultrasonic meters minimize long-term cost of ownership. They have no moving parts to wear out or collect debris, and require no regular maintenance or calibration. Titanium transducers are not affected by erosion from condensate droplets and will not fail due to thermal expansion cycles. For Casey Phelps, these were the crucial factors in deciding to go with an ultrasonic solution for the Washington, D.C. powerplant.

Ultrasonic theory

Compact ultrasonic transducers are either installed in a flowcell (spool piece) or directly in the steam pipe, one upstream of the other.

Transit-time ultrasonic flow meters take advantage of a simple principle, called “time of flight”, as illustrated in Figure 1.

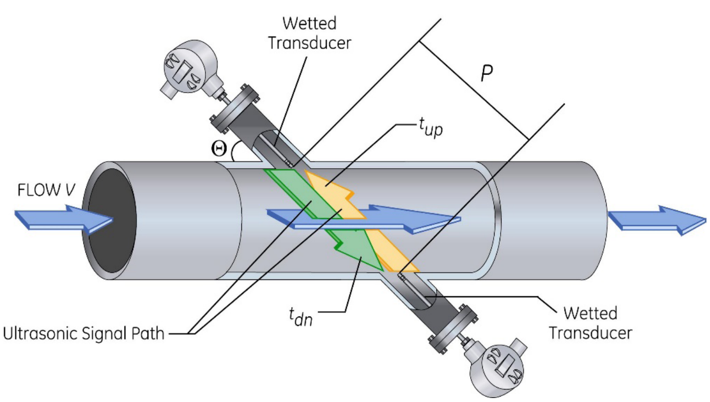


Figure 1. The operating principle of a transit time-based ultrasonic flow meter.

Specifically, the time it takes for an ultrasonic signal to travel against the flow (i.e., upstream), t_{up}, is longer than that it takes following the flow (i.e., downstream[1]), t_{dn}. The difference between upstream and downstream traveling times, Δt, is directly proportional to the flow velocity as follows:

$$V = \frac{P}{2\cos\theta}\left(\frac{1}{t_{dn}} - \frac{1}{t_{up}}\right) = \frac{P}{2\cos\theta}\left(\frac{\Delta t}{t_{dn}\, t_{up}}\right)$$

(Equation 1)

where V is the flow velocity to be measured, P is the ultrasonic path length, and 0 is the acute angle between the ultrasonic path and the axis of the flowcell or pipe section.

In Equation 2, volumetric flow, Q, is then calculated by multiplying the velocity of the fluid, V, by the cross-sectional area of the conduit, A, and a meter factor, K, which depends on the interrogation path and the flow profile, i.e.,

$$Q = K \times V \times A$$

(Equation 2)

In equation 3, mass flow, M, is further derived through the density of the fluid, ρ,

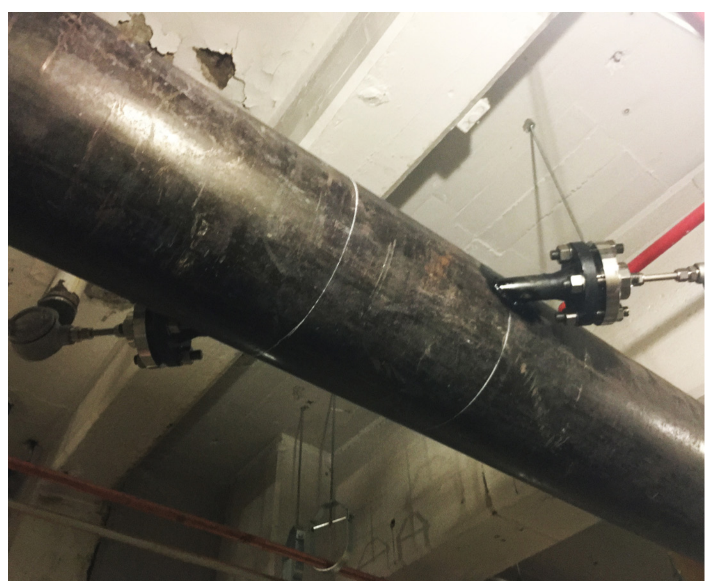
$$M = \rho \times K \times V \times A$$

(Equation 3)

In the case of steam, steam density, ρ, can be readily computed using a steam table if temperature, pressure and steam quality are known.

From Equation 1 it can be seen that the operation of an ultrasonic flow meter strongly depends on the timing of t_{up}, t_{dn}, and the dimensional measurement of path length P and angle 0. In addition, it can be seen that the flow velocity measurement is independent of the medium flowing inside the pipe.

In the case of steam flow measurement, steam can be treated as a hot gas when the steam quality is 1.0. As steam quality is decreasing, more water is present in the steam. The additional presence of water is absorbing sound, making it harder for ultrasound to propagate through the mixture. Eventually, as the steam quality is decreasing below 0.9, the steam is considered to be too "wet" for the ultrasound to pass through. As a result of this, an ultrasonic flow meter will lead to a loss of signal and output an error code to indicate the poor signal to noise ratio (SNR). Ultrasonic steam meters are well suited to make accurate flow measurement of steam with a steam quality between 0.9 and 1.0. Note that steam quality does not impact the transit time measurements of the sound waves, as long as sound can penetrate through the steam. Therefore, steam quality does not affect the velocity measurement as shown in Equation 1.



Steam cold tap installation

The transducers send and receive ultrasonic pulses through the steam. The meter measures the difference between the upstream and downstream transit times, and uses digital signal processing to calculate velocity and volumetric flow rate. The mass flow is then calculated from temperature and pressure inputs and built-in steam tables.

Bottom line

Both Hawthorne and Phelps see benefits from ultrasonic technology. For Yale University, an accurate measurement of steam flow leads to improved billing and a better understanding of steam consumption, which allows for improved efficiency on campus. “Repeatability of the data is paramount, and the quality of the electronics provide the consistency,” said Hawthorne. For his facility, Phelps noted that ultrasonic measurement delivers accurate and reliable data and combined with removable transducers, produces an overall lower cost of ownership.

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